Finite Element Modeling of Welding Processes
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Lecture - 39
Fundamentals of wire arc additive manufacturing processes-II

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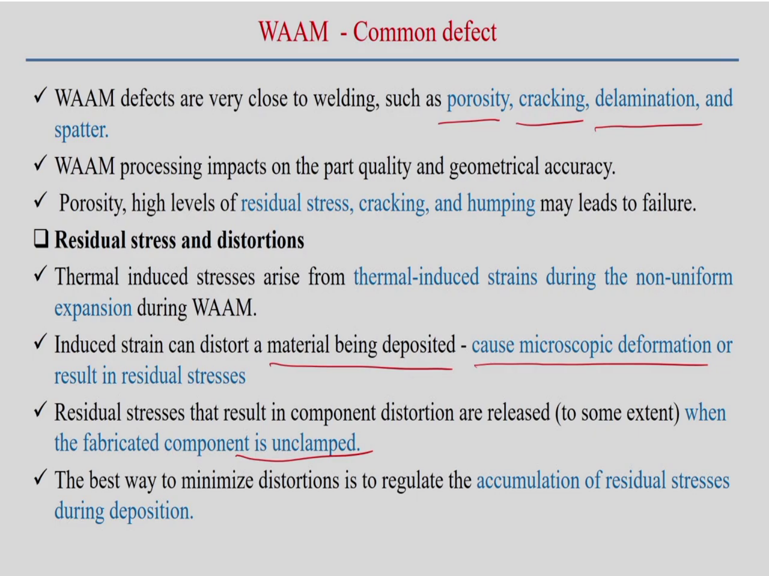

Hello everybody, now we will try to look into the in wire arc additive manufacturing process it is also associated with the some different kind of the common defects. So, most of the defects is may be associated with the related to the what we normally found in case of the welding process also fusion welding process.

That means, the defects kind of a porosity, this cracking, we can see the some kind of the delamination; that means, maybe the shrinkage may happen also. And, of course, during the welding that is we know this is the common for loss spatter.

So, the same kind of problem, or kind of difficulties, or kind of defects may also arise in case of the wire arc additive manufacturing process. But, of course, this defects all these things is necessary to analyze. Because finally, the accuracy of the part geometry depends on this or quality of the component depends on this; particular type of defects existence or not.

Therefore, apart from this thing porosity, high level of the residual stress also one kind of defect. Even some kind we can find out some kind of the, different kind of the cracking, solidification cracking also we can find out. And, as well as the humping; humping may also be possible to absorb in case of the wire arc additive manufacturing processes.

So, definitely all these kind of defects is sometimes this specifically the solidification cracking, and even residual stress they may leads to some sort of a formation of the failure of the component. So, therefore, you have to be very careful when you are designing the process choosing the particular process parameter.

So, all these kind of aspect has to be considered for proper designing of wire arc additive manufacturing process. Now, residual stress definitely when it is associated to some heat transfer is there and non uniform temperature distribution even as well as the contraction is there. So, the it is always associated with some sort of the residual stress generation in a structure.

So, that can mostly we normally say this is a thermal induced strain. During the non uniform expansion, or non uniform cooling also, during the cooling phase that is associated with the wire arc additive manufacturing process. So, now, induced thermal strain can lead to the formation of the kind of the residual stress.

But, this induced strain can be distort a material which is deposited. So, that amount of the strain generation may affect the distortion or may be associated with this particular process. But, it normally cause the microscopic deformation or the that particularly result in the residuals.

So, this strain the thermal strain is basically may cause some kind of the residual stress. But, of course, distribution can depends on the other parameters, other variation; some metallurgical effect is also associated for the formation of the residual stress. It means that the phase transformation phenomena also having some influence on this kind of residual stress generation.

Now, residual stress that result in the component distortion. Anyway, this distortion as well as the residual stress are there definitely both can be relaxed or to may be released to some extent when the fabricated component is unclamped. So, definitely than when it is clamped, so that actually induced some sort of with this there is a clamping is there even in the structure also. That means, it induced some sort of the residual stress in this particular structure.

But, when these unclamped then some sort of relaxation of the residual stress we can observe in a wire arc additive manufacturing structure. Now, the best way to minimize the distortion is to regulate the accumulation of the residual stresses during the deposition. That is very important because it is a layer by layer deposition process.

So, if it is possible to minimize the distortion then definitely we need to regulate the in the residual stress in the successive layers, or maybe you can say the successive deposition in that process.

So, if you control the residual stress, maybe to some extent we can we will be able to control the distortion in a in this particular component. Actually, this distortion and residual stress is one of the very common kind of the problem associated with the wire arc additive manufacturing process.

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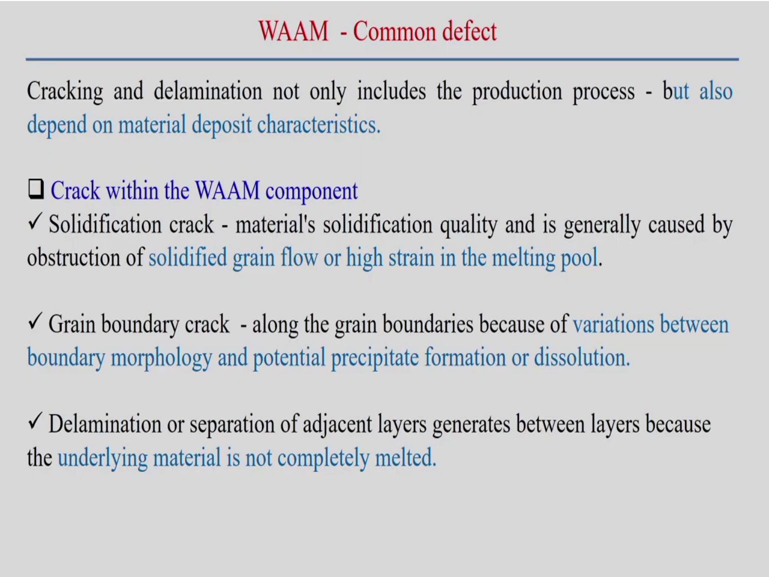

Now, cracking and delamination not only induces the production process, but also depend on the material deposit characteristic. So, it depends not only in the production process, even the cracking all these things also associated with the characteristics of the material deposition.

So, it means that, the material deposition strategy affect the residual stress and the cracking formation in the layer by layer deposition process. Now, crack within the wire arc additive manufacturing component can be of the different kind of the sources can be there. One is the solidification crack; that means, it is depends material solidification quality.

So, it specifically depends on the type of material and generally caused by the obstruction of the solidified grain flow, or high strain during the in the melting pool. So, if you look into the solidification behaviour also their solidified grain flow maybe care some kind of the obstruction in the flow. And, that can induce some sort of the solidification cracking.

Or, maybe in this case, so it this completely depends on the solidification behaviour of a particular material. So, in other sense we can say it is a more or less more material specific. Apart from this thing some grain boundary crack may also absorb in case of the wire arc additive manufacturing process. Because, along the grain boundaries the variation different kind of the grain boundary morphology is there.

So, and maybe potential precipitate formation, or some sort of the dissolution all actually influence some sort of the grain boundary cracking associated with the wire arc additive manufacturing process. So, apart from this thing delamination or maybe separation of the adjacent layer with respect to when depositing new layer how this layer behave with the already deposited layer.

So, sometimes they separate with respect to each other. And, then because there may be some sort of the not the underlining material may not properly melted. Such that, there is a issue to intimate mixing of the new deposited layer with the already existing layer.

So, that delamination or the separation may also happen and that is one of the kind of the problem associated with the wire arc additive manufacturing process. Typically, to understand this thing, so some sort of the thermal analysis may be useful here. Such that whether the previously deposited layer is very, the temperature achieve before depositing the next layer also.

So, that gap, or loss of the temperature after deposition all these kind of calculation helps to avoid this delamination or the kind of defect associated with the wire arc additive manufacturing process.

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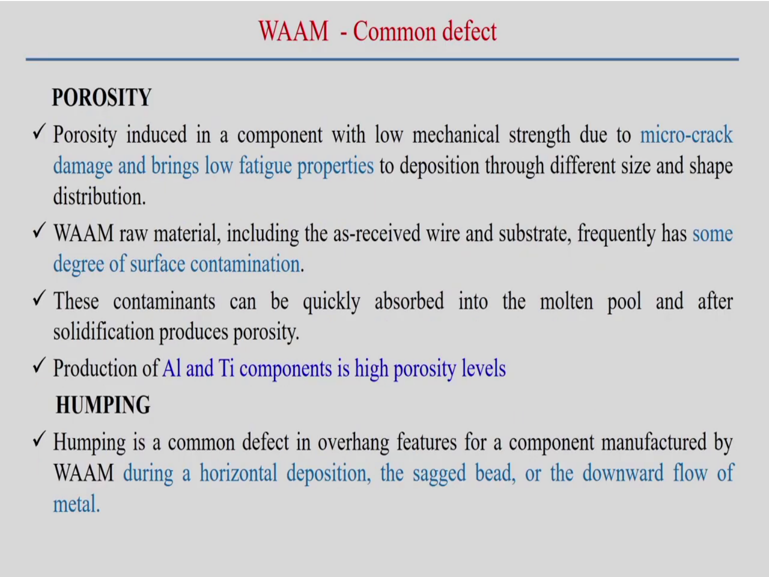

Now, apart from this thing porosity is another defect. Porosity basically induces, if you look into this particular PPTs also that component with the low melting strength. So, porosity is basically normally comes the induced because of the low melting strength material. And, due to the micro crack damage brings low fatigue properties to deposition through different size and the shape of the distribution.

So, then basically porosity induced distribute, this formation and this normally happens the this porosity can also happened interpret of the different gaseous medium here also. So, that clear some kind of the porosity formation. And, of course, it is a during the deposition process mostly associated with the formation of the porosity. And, actually induces some it’s induces this low fatigue properties.

So, presence of the porosity and it can induce some sort of the micro crack formation in this particular structure. Now, wire arc additive manufacturing raw material most of the cases the raw material as it is wire or substrate, frequently have the some degree of the surface contamination which is associated with the surface contamination. So, even in welding also if you want to get a very good weld joint normally, we do this do some kind of the surface preparation.

So, surface preparation means the remove the oxide layers, then we can expect very good well joint good properties can be expected. But, if we in presence of these presence of the oxides layer also that if we join this thing. So, this surface contamination can induce some sort of the not very good bonding of the material. So, that is very important.

So, surface level of the surface contamination before depositing the next layer has to be considered. And, may induce some sort of the porosity formation associated during the deposition process associated with the wire arc additive manufacturing process. So, these contaminants can be quickly absorbed basically the oxide layers mostly the into the molten pool and after solidification. Then, only this kind of a contaminated layer they actually create some kind of the porosity.

For example, we know that even if we follow normal the welding also then aluminum, titanium they are having very good affinity with to form some kind of the oxides.

So, therefore, extra protection in the sense that some sort of the shielding gas is required to perform the welding of the aluminum or titanium. Specifically, I am talking about the fusion welding process. So, therefore, the similar kind of the problem may also arise in case of the wire arc additive manufacturing process.

Apart from this thing humping is another defect kind of the defect. So, basically humping is the common defect it is a specifically, overhang when you try to develop some kind of the overhang feature associated with the wire arc additive manufacturing process.

There we can look into this thing when you try to follow some kind of the horizontal deposition, then humping may happen during this deposition process. So, it is a simply the sagging bead kind of a profile it can create during this process. So, that we can consider as a common defect associated with the wire arc additive manufacturing process.

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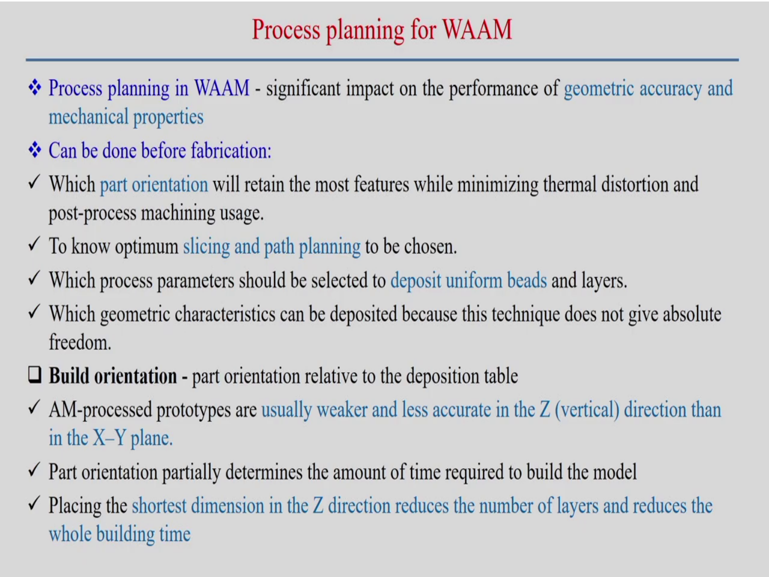

Now, apart from this thing to some overall idea of maybe understanding the wire arc additive manufacturing process, that is the associated with the process planning.

So, it is very important the process planning means, how we can generate the process path, and then how we can plan the path through which the deposition can be followed. So, that is very important aspect in case of the arc additive manufacturing process, or designing of this path is very, we can say one of the critical component associated with the wire arc additive manufacturing process.

Now, process planning in wire arc additive manufacturing process the significant impact on the performance of the geometric accuracy. It is very important because, geometric accuracy after deposition what kind of the surface finish or resolution we can achieve that can be influenced by the process planning. So, geometric accuracy and the mechanical properties of course, apart from this thing the indirectly it also affect the mechanical properties of a layer by layer deposition process.

Now, something can be done before the fabrication in the process planning such that we can achieve a very good deposited layer, or we can achieve very good mechanical properties, or achieve very good resolution of a particular printing process. Now, it can be done before fabrication, but one is the important thing is a part orientation.

So, which part orientation will retain the most features that can be features while minimizing the thermal distortion, and post processing machining use. So, we have to focused on the that one part orientation, definitely you look into the part orientation. But, that part are having maximum features is associated with this thing. Such that, we can target this particular feature, or part orientation such that the thermal distortion and the machining, post processing machining process can be minimized.

Apart from this thing to know, the optimum slicing and path planning to be chosen. To know, because if you know the optimum slicing, because first you have to there is a link that the slicing what way we can follow the strategy for the slicing of a particular process so that is basically associated with the path planning.

So, it is a link basically, so optimum path, optimum slicing having some influence or having some link with the path planning also. Now, apart from this thing which process parameters we should know, which process parameter influence more that can be selected to deposit uniform beads and layer. So, definitely we look into this particular parameters, process parameters that will try to make some kind of the uniform deposits selected the uniform beads, try to form the uniform beads and uniform layer.

So, that kind of the process parameter also we need to identify such that, we can adopt these particular process parameters to incorporate in the weld design, process planning process. Apart from this thing, which geometric characteristics can be deposited and because, this technique does not give the absolute freedom. So, that is why geometric characteristics can be deposited that has to be some we have to look into this particular aspect such that process planning can be done effectively.

Now, build orientation; build orientation means, part orientation with respect to the deposited layer. So, in which orientation we can be; it can be done, which direction the orientation can be performed. So, additive manufacturing process prototypes usually weaker and the less accurate in the Z direction so, than the X-Y plane. So, basically that information is helpful to designing the process planning.

Part orientation partially determines the amount of the time required to build the model also. Again, it is associated with, this part orientation is also associated with the this thing, to what is our total amount of the time require that to build a particular model.

So, that kind of the calculation is also possible and it is also associated with the part orientation. Apart from this thing, placing the shortest dimension it is also possible, the shortest dimension along the Z axis Z direction, and it actually reduces the number of layers in the Z direction. So, therefore, since the weak this if you see the usually weaker in the less accurate in the Z direction.

So, therefore, we try to minimize deposition layer along the Z direction and we can give more freedom, more complex features in the X and Y direction. So, in that way apart from this things we can capture the features accurately, apart from this thing we can minimize the time require if we put the shortest dimension along the Z direction.

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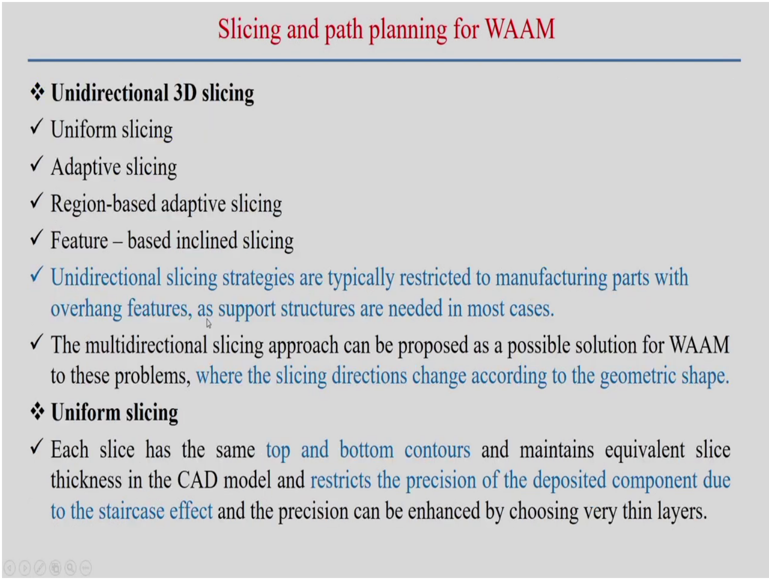

Now, slicing and path planning of wire arc additive manufacturing process there is a unidirectional 3-dimensional slicing is normally follow. So, in this case the uniform slicing is followed, so uniform layer thickness we follow all these things and that thing. And, some cases depending upon the complexity of the problem adaptive slicing can also be followed.

And, this apart from this region based adaptive slicing, feature based adaptive inclined slicing can be also followed depending upon the geometric profile. Therefore, unidirectional slicing strategies are typically restricted to manufacturing parts basically, so basically manufacturing component.

So, in that cases unidirectional slicing strategies are more important. And, having some kind of the overhang features and there is a need some kind of the support structure in particular that cases the unidirectional slicing strategy is most useful. Apart from this thing, the multidirectional slicing strategy approach can also proposed as a possible solution for the wire arc additive manufacturing process.

Where, the slicing direction change according to the geometric shape. So, definitely the slicing direction change according to the geometric shape, in this particular situation the multi directional slicing approach can be adaptive. And, the same strategy can also be followed in case of the wire arc additive manufacturing process. Now, apart from this thing uniform slicing. So, uniform slicing is the each slice has the same top and bottom contours and maintains equivalent slice thickness in the cad model.

So, that is normally called as the uniform slicing process. And, restrict the precision of the deposited component due to the staircase effects. So, if you look into the each slice having the top and bottom contours and maintains almost the equivalent almost equal equivalent or equal thickness. In that cases it can eliminate the staircase component which is normally associated with the additive manufacturing process.

Staircase means, so one deposited layer, the next deposited layer. So, that can be formed if you want to make a very round part. So, that cad form in the form of the staircase deposited layer. Now, this staircase effect can be restricted using this uniform slicing.

But, other thing is that once we restrict to the uniform slicing the only possibilities is that, if you reduce the slice thickness. But, or other way also there may be enhancement of the built time if you follow if you reduce the slicing thickness. So, that can also be observed associated with this uniform slicing.

Apart from this thing adaptive slicing is also there, this approach uses the parallel slices. So, it use the parallel slices, but parameters, surface finish, and the cad geometry curvature in the deposition direction, particular direction are determined by the slice thickness.

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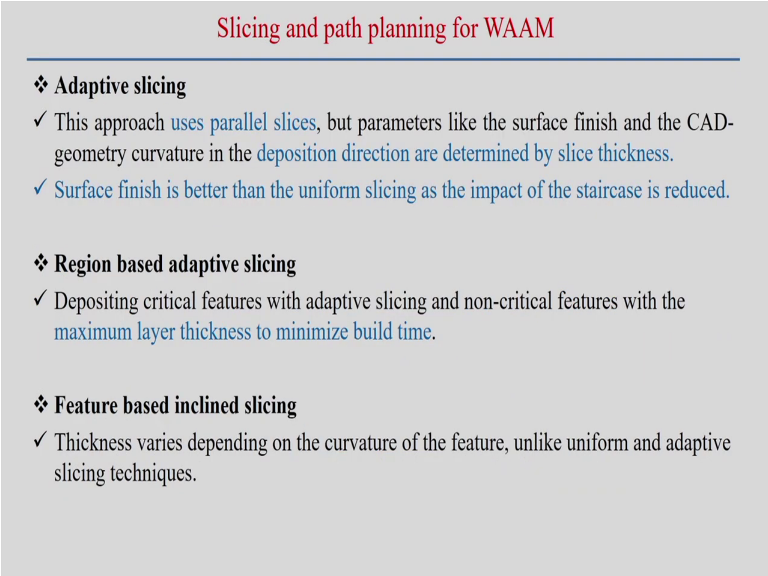

So, definitely in these cases the surface finish, and the geometry curvature, the deposited direction exactly influenced by the slice thickness in case of the, this particular process. Therefore, if we want to achieve better surface finish then uniform slicing as impact of the staircase is reducing. So, surface finish is better if you follow the adaptive slicing.

So, it adaptive slicing means, if you want to achieve some kind of a surface roughness, then accordingly there is a change of the slice thickness. And of course, it depends on the features; it depends on the geometric features of this particular component.

So, that is why accordingly it is a different kind of the strategy can be followed to achieve the particular, or to enhance the improve the surface finish in this particular in adaptive slicing process. Now, apart from this thing region based adaptive slicing basically, one particular region when there is a need to make a very complex features are there.

So, to achieve this complex features probably in this very localized position, then in that cases the slice thickness can be reduced. So, that we can achieve the more accurate reproduce this particular complex component. So, depositing critical features with the adaptive slicing and non critical features with the maximum layer thickness to minimize the build time.

It means that, that when there is a need some very critical features are available, require if there we can reduce the slice thickness, or you can follow the adaptive slicing. And, when it is the non critical features there you can see the slicing thickness can be much more such that build time can be minimized in this particular case.

So, that kind of region based adaptive slicing is also one of the way to optimize the slicing process. Then, feature based inclined slicing; in this case thickness can vary depending upon the curvature of the feature unlike uniform and the adaptive slicing. Apart from the uniform adaptive slicing techniques, there may be possibility of thickness can also vary depending upon the curvature.

So, that is called the feature based inclined slicing. So, that kind of the slicing strategy can also be adopted in case of the wire arc additive manufacturing process.

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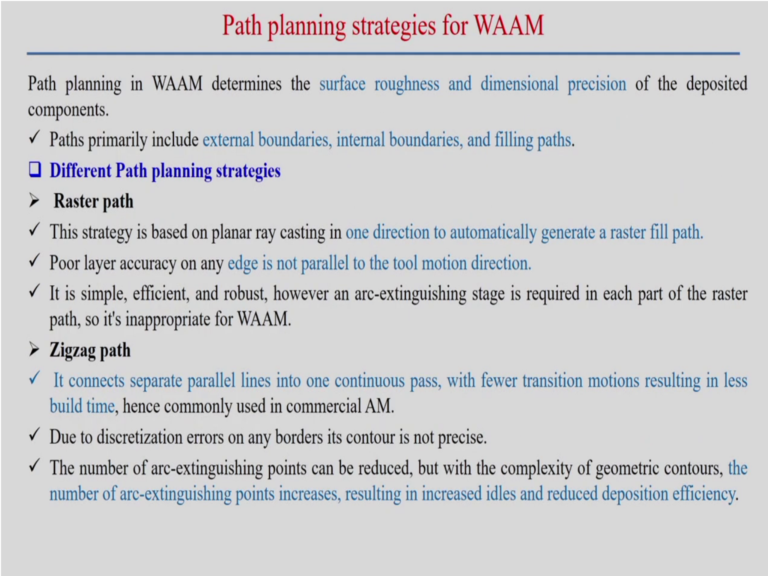

Now, path planning strategies for the wire arc additive manufacturing process. We can we have seen the path planning in wire arc additive manufacturing process, actually determines the surface roughness, and the dimensional precision of the deposited components. So, therefore, this paths primarily include the external boundaries, internal boundaries, and basically the filling paths.

So, or looking into that internal boundary what is the external boundary of a particular component, how we can fill the in between area. So, that takes care of this with the effective path planning process of wire arc additive manufacturing process.

Now, normally wire arc additive manufacturing process there are different kind of the path planning strategies, one is the raster path. This strategy is based on the planer ray casting in one direction automatically generate raster fill path. So, basically poor layer accuracy on the edge, and is not parallel to the tool motion direction, so that kind of the difficulties is there in this particular raster path.

Although, it is simple, effective, but may not be applicable in case of the wire arc additive manufacturing process. Apart from this thing, there are some zigzag path also there. So, it connects the separate parallel line, so there are separate parallel lines it connects into one continuous pass. And, the there may be some fewer transition resulting in the less build time, hence commonly used for commercial additive manufacturing process.

So, this zigzag path is commercially using is usable in commercial additive manufacturing process. But, due to the discretization errors on any borders it contours may not be very precise what is expected in in case of the other cases.

But, the number of arc extinguishing points, because wire arc additive manufacturing process therefore, are there are so many arc extinguished process point may be there. So, in this case the number of arc extinguishing points can be reduced if we follow the zigzag path. But, it depends on the complexity of the geometric contours.

But, at the same time the number of extinguishing points increases depending upon the complexity of the geometric contours. Definitely, the two complex the number of extinguish points can be much more. And therefore, resulting in the increase ideals and the reduced deposition efficiency, so the deposition efficiency can be unless in this particular case.

So; that means, in case of if we increase if we try to make the feature is a very complex geometry. So, that may be difficulties associated with the wire arc additive manufacturing process.

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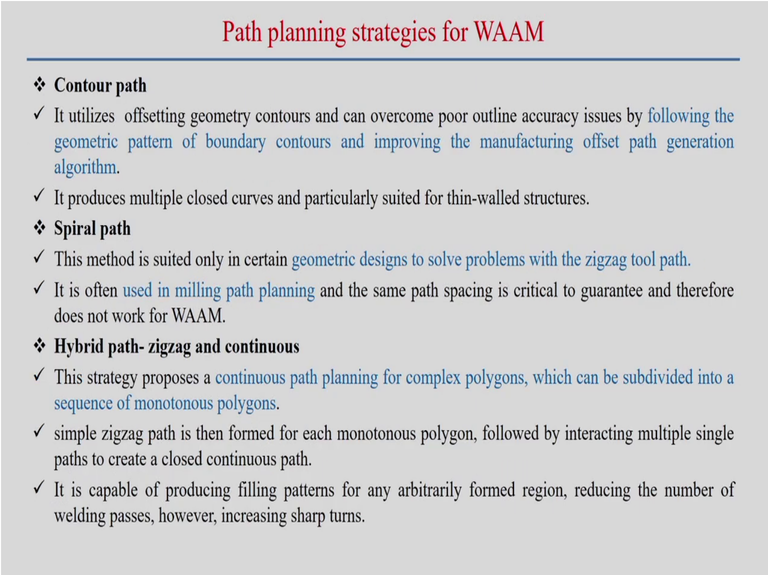

Now, apart from this thing there is a contour path, contour path it utilize a basically offset geometry kind of offset geometry contours and can overcome the poor outline accuracy. So, basically poor accuracy level can be enhanced if we follow some kind of the contour path.

In this case it normally follows the geometric pattern of the boundary contours, and improving the manufacturing offset path generation algorithm. So, in this case basically we handling the offsetting the geometry contours, we normally follow the strategy of the contour path. It produces the multiple closed curve that is possible to produces. And, particularly in this particular process contour path is suitable in case of the thins walled structure in that cases this contour path is more applicable.

Apart from this thing, there is a spiral path spiral path this method is basically suited in case of the certain geometric design. So, it is a movement the spiral path can be followed in specific geometry to solve problems with the zigzag tool path. So, there is a where there is a difficult in the zigzag tool path. So, there we can follow some kind of the spiral path.

This is often used in the milling path planning process and the same path spacing is used and also critical to guarantee. And therefore, does not work for wire arc additive manufacturing process.

Actually, it is very difficult to make the spiral path is associated with the wire arc additive manufacturing process. Apart from this thing, there is a hybrid path, zigzag and continuous path planning can also be followed. Actually, this strategy produces the continuous path planning process, but for complex polygon which can be subdivided into the sequence of the monotonous polygon. So, there is a this complex polygon in that cases we can follow this hybrid path.

But, in this case simply zigzag path is often form and each monotone, for each monotonous polygon. And, then followed by the interacting multiple single paths to create a closed continuous path, so that is normally followed in this case. And, it is also capable for producing the filling the patterns for any arbitrarily formed region, reducing the number of welding process, but increasing the sharp turns.

So, that is the one difficulties here also, because in these cases it can increase the sharp turn associated with the hybrid path. So, definitely if you look into that contour path, spiral path, and maybe hybrid path all depends upon the what are the strategy. What are the complex geometry we are handling based on that we can decide the strategy. And, according strategically we can make some kind of the path planning associated with wire arc additive manufacturing process.

But, remember there are these so many path planning process are available. But, some path planning process may be very much a suitable in case of the handling the laser based additive manufacturing process when handling the powder material. But, not all these path planning is suitable in case of the wire arc additive manufacturing process.

So, there may be some limitation or maybe depending, because wire arc additive manufacturing process is mainly associated with the when you try to make some kind of the very large size product. And, then it is a very small features, very kind of very fine surface finish we cannot expect in case of the wire arc additive manufacturing process.

So, therefore, to look into this aspect probably accordingly we can divide the path planning strategy such that the build time all this effect, or as close as we can reproduce the geometric feature in this particular by designing the proper path planning in case of the wire arc additive manufacturing process.

So, that is all for this some overview of the wire arc additive manufacturing process. But, actually in details we can follow some kind of the additive manufacturing technology, there we can get much details of the wire arc additive manufacturing process. So, thank you very much for your kind attention.